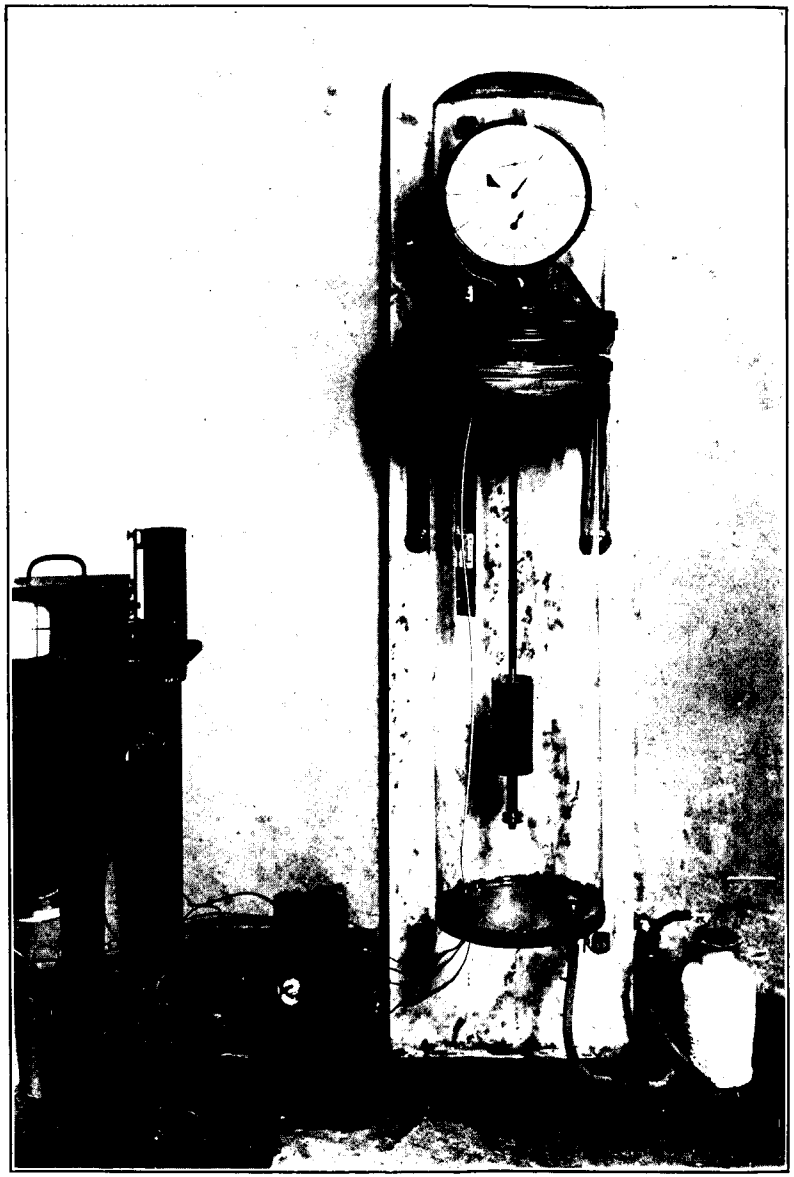

FIGURE 1.—*Precision mean time clock (Riefler type) used as a standard in the testing of timepieces at the National Bureau of Standards*

This clock is kept at constant temperature and pressure and keeps time to an accuracy of about 0.02 second a day.

U. S. DEPARTMENT OF COMMERCE
R. P. LAMONT, Secretary
BUREAU OF STANDARDS
GEORGE K. BURGESS, Director

CIRCULAR OF THE BUREAU OF STANDARDS, No. 392
Supersedes Circular No. 51

TESTING OF TIMEPIECES

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TESTING OF TIMEPIECES[1]

ABSTRACT

This circular describes in detail six standard tests for watches and chronometers adopted by the National Bureau of Standards. These tests consist of four tests for pocket watches—namely, "class A," "class B," "railroad precision," and "business precision"— a short test for stop watches, and a short test for chronometers. Suggestions regarding the use and care of a watch, a list of official stations which send out radio time signals, information regarding standard time and standard time zones, directions for the submittal of timepieces for test, and other items of general information are also given.

CONTENTS

I. INTRODUCTION

The functions of the National Bureau of Standards include the testing and comparison with standards, of various kinds of measuring apparatus, and the certification of the accuracy of such instruments. Included in such measuring apparatus are timepieces of various kinds, such as pocket watches, wrist watches, stop watches, chronometers, clocks, and chronographs.

In deciding upon the forms of tests to be given the bureau has had in mind chiefly the value of the test to the users of timepieces. It is well known that all timepieces vary somewhat from correct time.

[1] Prepared by Ralph E. Gould, chief, time section.

The most careful adjustment can not entirely eliminate this variation. For example, the isochronism, or the uniformity of rate as the watch runs down, is dependent upon the poise of the balance, and, consequently, a watch carefully adjusted to give a perfect isochronal rate in one position may have a variable rate when changed to another position.

Circular No. 51 on Measurement of Time and Tests of Timepieces, which this circular supersedes, was issued by the National Bureau of Standards in 1914. Since this time, changes in, and additions to, the tests have been made which justify the preparation of a new circular. This circular, as in the case of the previous one, is confined largely to a description of the methods and procedure followed at the National Bureau of Standards in testing timepieces. The tests and tolerances involved in the certification of pocket watches, stop watches, and chronometers are given in detail. The regulations under which such tests are conducted and the general instructions covering the submittal of timepieces for test are given.

The data given in the test report may be used to advantage in securing a better pocket performance of the watch, by avoiding those positions and temperatures for which it has the poorest rates. Satisfactory performance under test assures the owner that the watch is free from defects which are likely to effect its value as a timekeeper under reasonable conditions of service.

The tests also furnish information as to the relative performance of various grades and makes of timepieces, and particularly as to the value of any special features or improvements that may be introduced into their manufacture.

A certain amount of general information is included in the Appendix on the subjects of standard time, time signals, time zones, and also on the use and care of a watch.

II. DEFINITIONS

Correction.—In the rating of a timepiece, the "correction" is the amount of time to be added algebraically to the reading of the instrument at any instant to give the correct time. As most timepieces in common use indicate mean solar time, the corrections are always such as to give the correct mean solar time. If a watch is slow, its correction is plus, and, if fast, its correction is minus.

Daily rate.—The "daily rate," or more simply the "rate," is the amount of time gained or lost in 24 hours. It is found by subtracting the correction at the beginning of the 24-hour period from the correction at the end of that period. If this difference is negative, a gaining rate is indicated, and if positive, a losing rate.

Signs.—In the National Bureau of Standards and other national testing laboratories it is customary to regard a gaining timepiece as having a minus (−) rate, and a losing timepiece as having a plus (+) rate. It is understood, however, that in American factories the opposite practice is generally followed; that is, a gaining timepiece is regarded as having a plus rate, and a losing timepiece as having a minus rate.

Difference in rate per degree change in temperature.—In determining the "difference in rate per degree change in temperature," the rate at the lower temperature is subtracted from that at the higher temper-

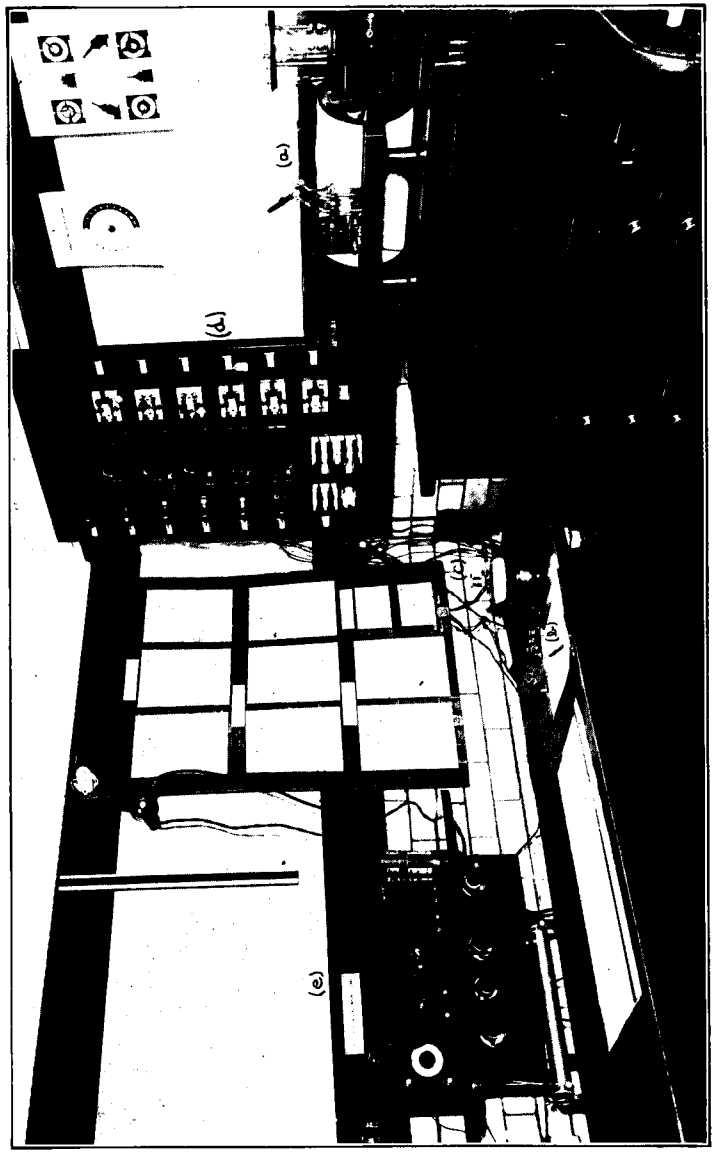

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FIGURE 2.—*A corner of the time laboratory*

(*a*) The chronograph upon which readings are recorded; (*b*) the telegraph key; (*c*) the electrically operated time stamp; (*d*) the switchboard for distributing the signals from the Riefler clock to other laboratories; and (*e*) the radio set for receiving the time signals from the Naval Observatory.

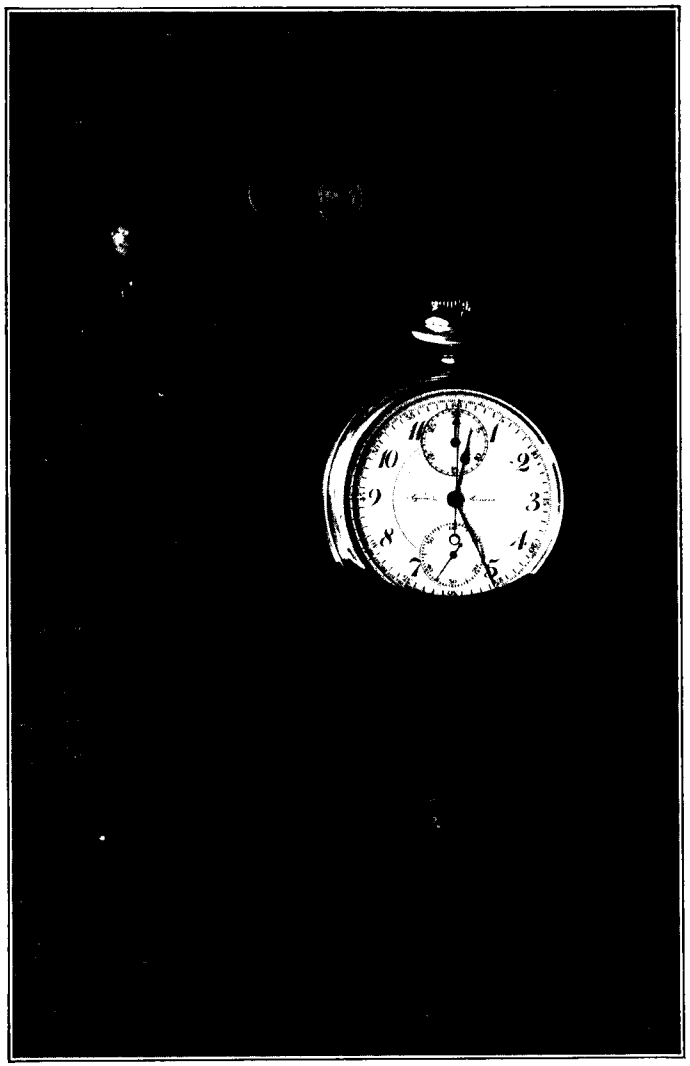

FIGURE 3.—*Special key used in the testing of stop watches to eliminate personal errors*

The key is pressed against the crown of the watch to start and stop it, causing an electric contact to be made at (*c*), and operating the pen of the chronograph so that it makes a record of the time of starting and stopping the watch.

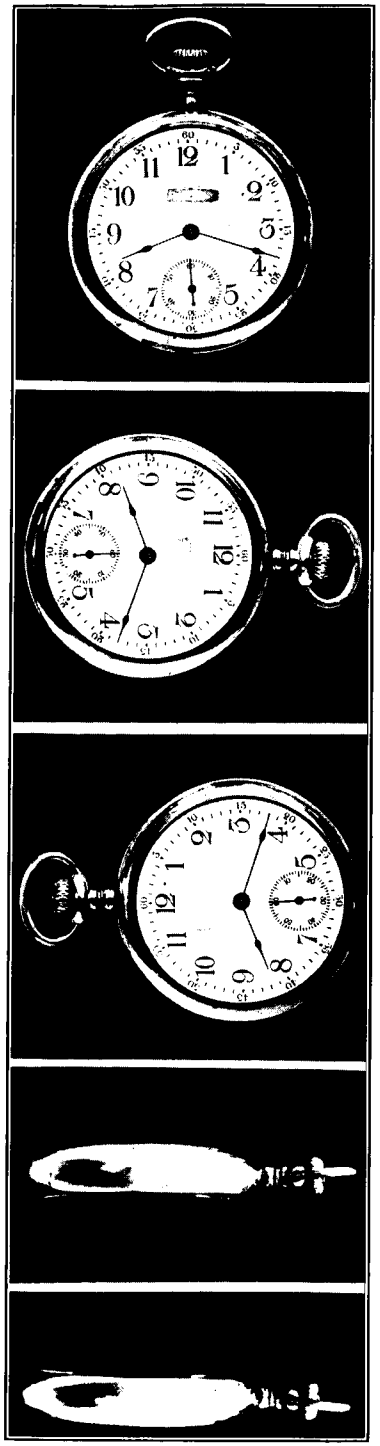

FIGURE 4.—*Five positions in which watches are tested*

(*a*) Vertical, pendant-up; (*b*) vertical, pendant-right; (*c*) vertical, pendant-left; (*d*) horizontal, dial-down; (*e*) horizontal, dial-up.

ature, and the result is divided by the difference in temperatures. The meaning of the signs obtained is the same as for daily rate.

III. CHARACTER OF TESTS OF TIMEPIECES

The testing of timepieces consists of the determination of their daily rates under the various conditions for which they are adjusted. From the results several criteria are computed to determine whether the performance is such as might reasonably be expected from a properly adjusted timepiece. The daily rates are obtained by comparing the indication of the timepiece under test with that of the standard clock. In making a comparison the daily readings are recorded on a chronograph (fig. 2), which also records time through the electric seconds contact of the bureau's mean time clock (fig. 1), by tapping a telegraph key when the second hand of the timepiece reaches a given point of the dial. It is easily possible in this way to obtain the correction each day to within 0.1 second. As the readings are made at the same point on the dial each day, the effect of any error in graduation of the dial or eccentricity of the position of the hand is avoided. Furthermore, the comparisons being made at the same time each day, within a few minutes, the daily rate is obtained at once without further correction, other than possible small variations in the standard, which is checked daily. The timepieces are wound each day just before they are read, so that isochronal variations are not introduced into the daily readings.

The signals from the bureau's standard clock are compared daily by radio with those sent out by the Naval Observatory in Washington, D. C., to ascertain any error in the indication of the standard clock.

1. POSITION TEST

The better grade of watches are usually adjusted for 3 or 5 positions, to isochronism, and for temperature variations. While some watches, mostly of foreign make, are adjusted for 2, 4, or 6 positions, the 3 and 5 position watches are much more common. Accordingly, two classes of tests have been adopted, one for the 5-position and the other for the 3-position watch. The 5 positions for which watches are generally adjusted are (*a*) vertical, pendant-up; (*b*) vertical, pendant-right; (*c*) vertical, pendant-left; (*d*) horizontal, dial-up; and (*e*) horizontal, dial-down. (See fig. 4.) In the 3 position, adjusted watches, the pendant-right and pendant-left positions are usually omitted.

The test for position adjustment consists of running the watch for several days in each of the 3 or the 5 positions. The test is conducted under temperature conditions as constant as possible in order to eliminate from this test any irregularities due to temperature variations. The rates are taken for several days in each position to ascertain the degree of uniformity of rate on successive days. In the class A and the class B tests, described later, special emphasis is placed upon this uniformity of rate.

It has been found by tests that most watches have a progressive change in rate, usually a slowing up. It is desirable to eliminate the effect of this progressive change in rate as much as possible in determining the true precision of the position adjustment. This is done in the class A and class B tests by repeating the series of position tests in

reverse order. The mean of the two sets of rates for each position is taken as the mean rate for that position. The difference between the mean rates of the two periods in the same position gives the progressive change in rate for the time between the two periods.

The accuracy of the position adjustment is judged primarily by the deviations of each of the mean rates for the various positions from the average of these mean rates. Certain tolerances are allowed for the maximum difference in rate for any two positions, and also for the differences between the mean rates of the more important positions—vertical, pendant-up; horizontal, dial-up; and horizontal, dial-down.

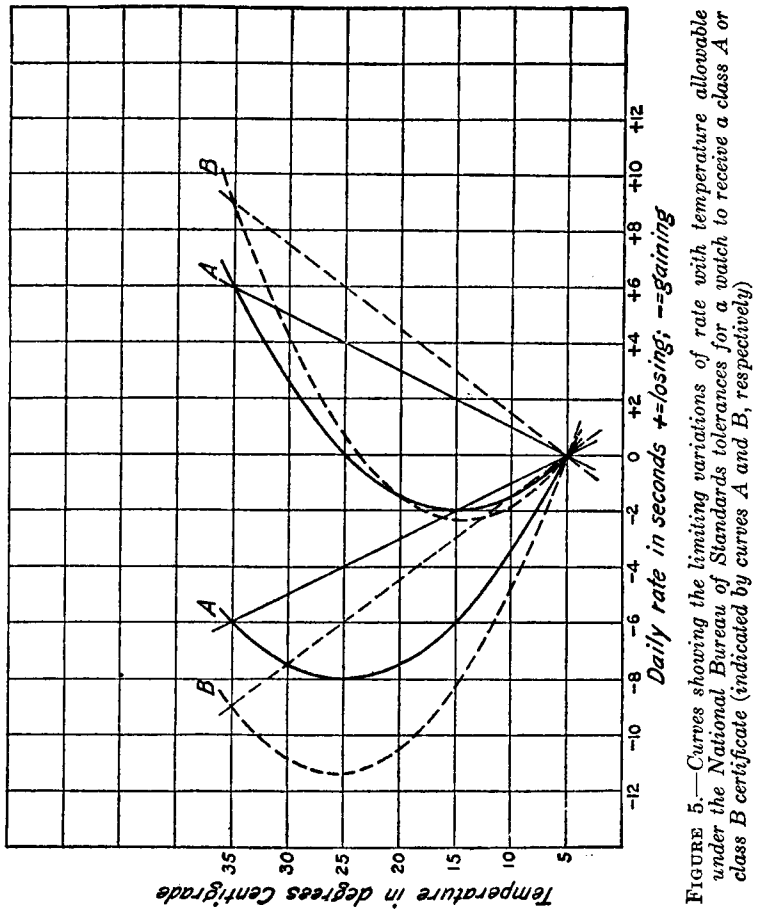

FIGURE 5.—*Curves showing the limiting variations of rate with temperature allowable under the National Bureau of Standards tolerances for a watch to receive a class A or class B certificate (indicated by curves A and B, respectively)*

2. TEMPERATURE TEST

In the tests for temperature adjustment the timepieces are usually run for several days at each of three temperatures approximating 5°, 20°, and 35° C. (41°, 68°, and 95° F.). The tests are conducted in cabinets in which the temperature is maintained constant by thermostatic control. In all cases where a timepiece is tested at more than

one temperature, an intermediate day is allowed after each temperature change to permit the instrument to adjust itself to the new temperature.

In interpreting the results of the test for temperature compensation, it should be remembered that it is practically impossible, especially with the ordinary brass and steel balance wheel and steel hairspring, to reduce the variation of rate with temperature to a linear function, and at the same time keep the change of rate small.

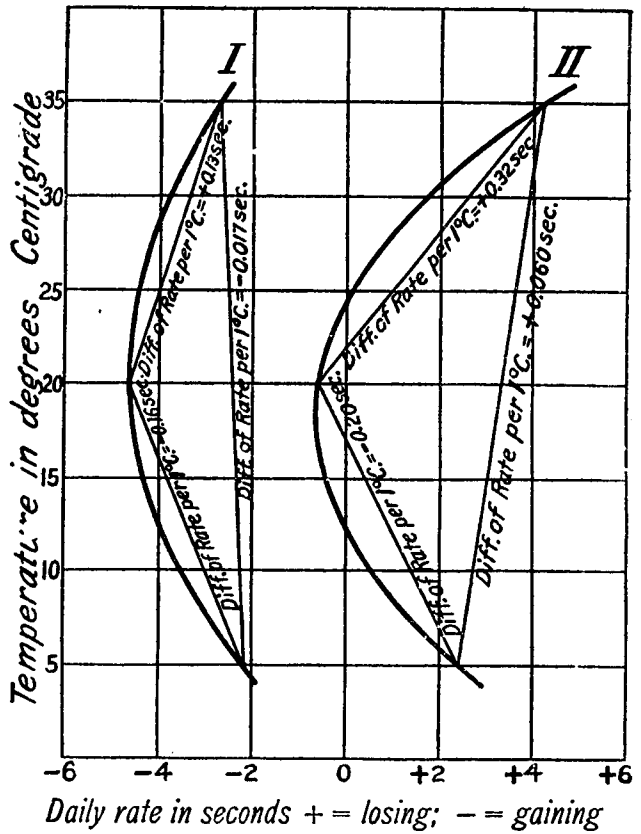

FIGURE 6.—*Temperature curves of watches*

Curve *I* is that of an exceptionally well compensated watch with a brass-steel balance wheel; Curve *II* shows an average performance of a watch meeting the requirements as to temperature compensation for a National Bureau of Standards class A certificate.

The variations that take place usually follow approximately the form of a parabola, and the adjustment of the timepiece is so made as to bring the point of greatest gaining rate as near as possible to the temperature at which the timepiece is ordinarily used and to make the rates at the high and low temperatures approximately equal. Consequently, with a given balance wheel and hairspring, practically all that can be done is to make the rate at the high temperature (35° C.) equal to the rate at the low temperature (5° C.), and to let the rate at the medium temperature (20° C.) be what it may. The adjuster,

therefore, is chiefly interested in the difference between the rates at the high and low temperatures, and in the general slope and flatness of the curve, while the user is concerned in knowing what the rate of the watch is at the various temperatures.

3. ISOCHRONISM TEST

Isochronism, or the uniformity of rate as the watch runs down, is determined from readings taken every hour or two during the first

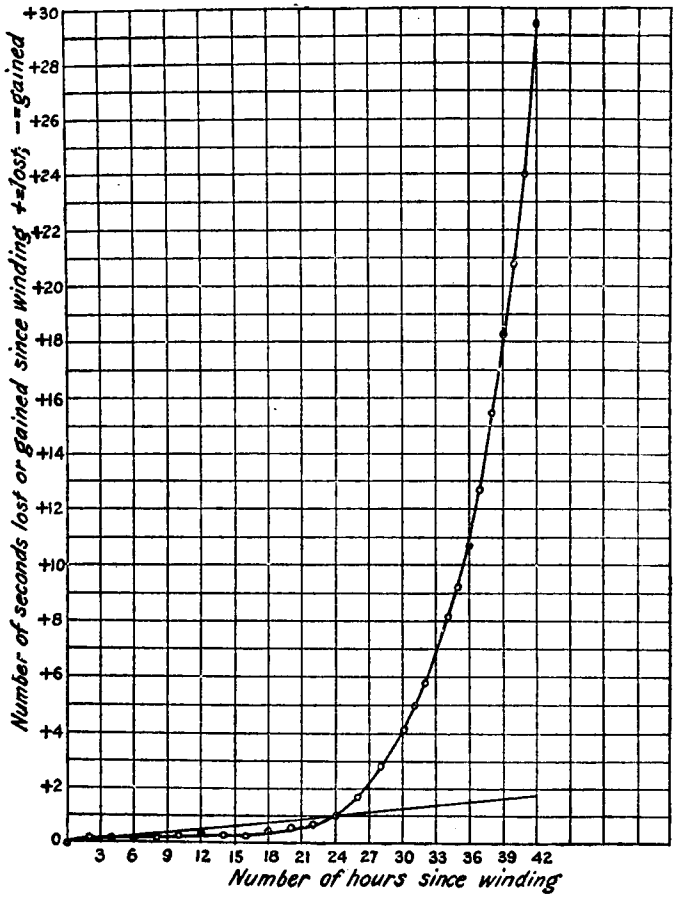

FIGURE 8.—*Isochronism curve of a watch well adjusted for isochronism for the first 24 hours after winding, with only small errors during that time, but showing a marked change in rate after 24 hours*

36 hours after winding, the timepiece being wound only at the beginning of the test.

Watches are tested for isochronism in the vertical, pendant-up position as that is the position in which they are generally carried, and therefore the position in which isochronism is of most importance, although a nearer approach to true isochronism can usually be obtained with the watch in the horizontal position. The isoch-

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FIGURE 7.—*One of the cabinets in which timepieces are tested at controlled temperatures*

This cabinet, with others, makes it possible to conduct tests at controlled temperatures anywhere between −50° C. and +50° C.

ronism test for chronometers is conducted with the instrument in the horizontal, dial-up position, which is the normal operating position for this type of timepiece.

Although a fair isochronism adjustment can be expected only for the first 24 hours, the test is continued for the longer period to show more clearly the changes in rate that may occur after 24 hours. Any attempt to secure isochronism for more than 24 hours usually results in the sacrificing of isochronism for the first part of the run.

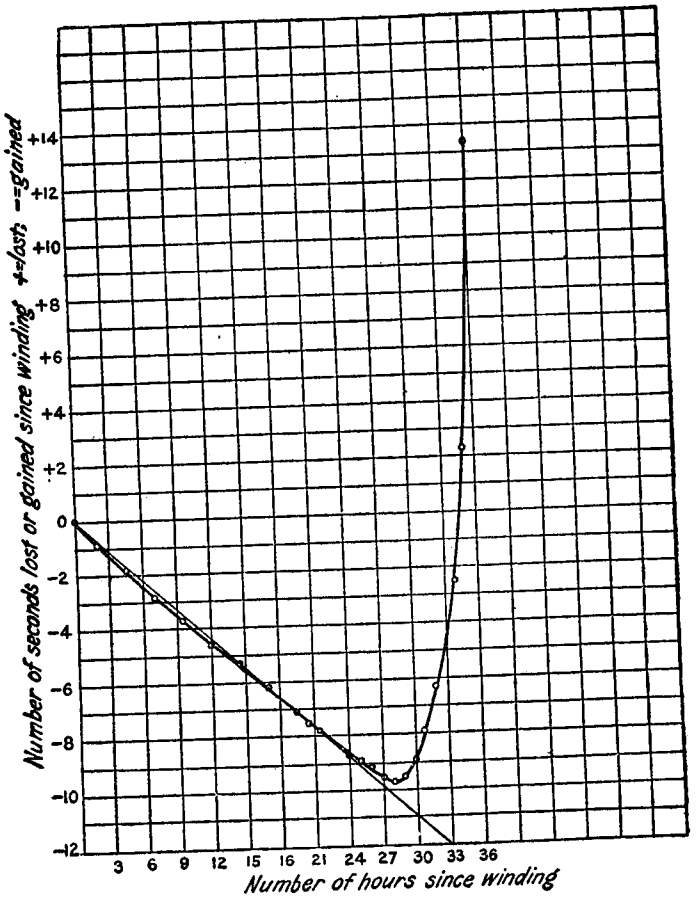

FIGURE 9.—*Isochronism curve of a watch well adjusted for isochronism for the first 24 or 28 hours after winding, but showing a marked reversal of rate after the twenty-eighth hour point*

The character of the variations after the first 24 hours depends largely upon the methods used to secure isochronism. For some timepieces the rate continues in the same direction as during the first part of the test but increases rapidly, while for other timepieces there is a sharp reversal of rate within a few hours after the twenty-fourth. The rate as the spring runs down often increases to several times the earlier rates.

Figures 8 and 9 are typical examples of isochronism curves of watches well adjusted for isochronism during the first 24 hours after winding. but showing marked changes in rate shortly after that time. Figures 10 and 11 illustrate poor adjustment during the first 24 hours, and show irregularities of rate after that time. The correction—that is, the number of seconds gained or lost since winding—is shown by the vertical ordinates of the curves, while the elapsed time is plotted

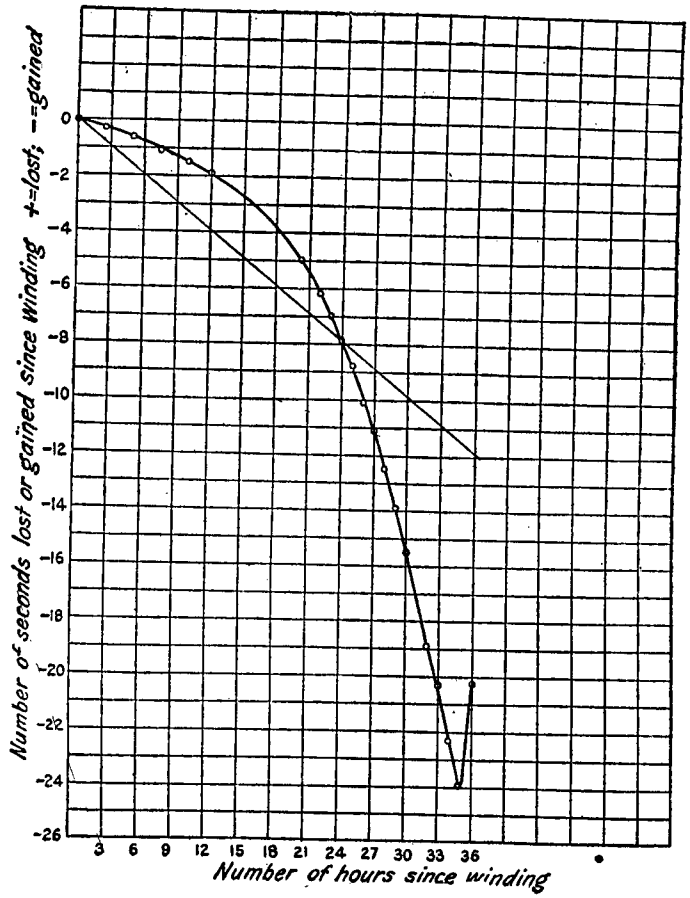

FIGURE 10.—*Isochronism curve of a watch poorly adjusted for isochronism and exhibiting a steady increase in rate after the 24-hour point except for a reversal of rate in the last hour before the watch stopped*

horizontally. A straight line drawn from the zero point through the 24-hour point of the curve is taken to represent true isochronism for the observed 24-hour rate. The vertical differences between this straight line and the curve may be taken to indicate the isochronism error at any time during the test. In the standard tests the isochronism error is taken as twice the error at the 12-hour point subtracted from the error at the 24-hour point.

These curves indicate the importance of regular daily windings and the variations that may be expected when the intervals between windings are irregular.

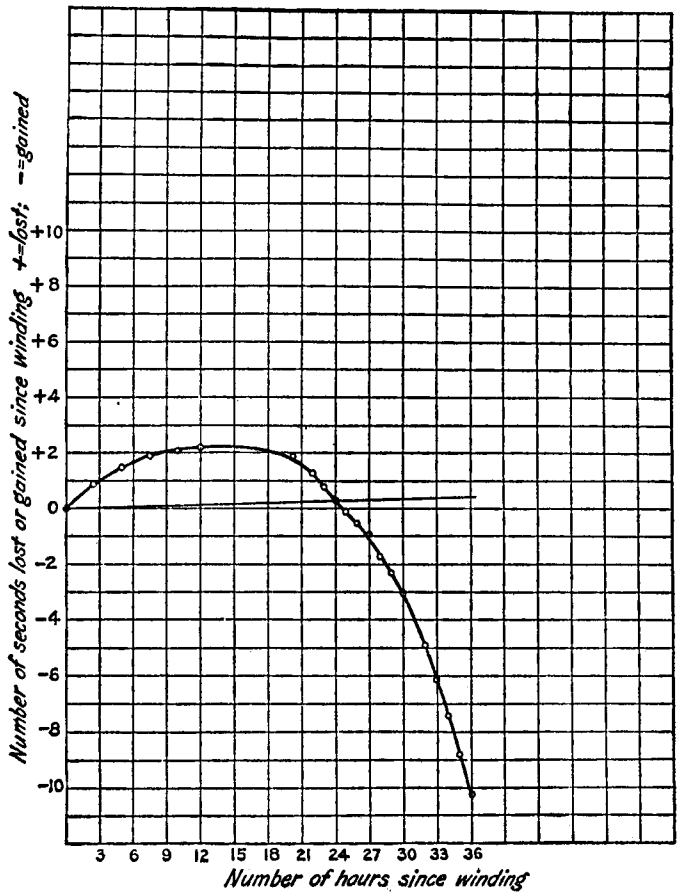

FIGURE 11.—*Isochronism curve of a watch poorly adjusted for isochronism*

The daily rate is only +0.3 second, but at the end of the first 12 hours it is in error by more than 2 seconds and in the 12 hours after the twenty-fourth it gains 10.5 seconds.

IV. DESCRIPTION OF TESTS

Detailed descriptions of the various standard tests adopted by the National Bureau of Standards for the testing of timepieces are given in the following paragraphs.

1. CLASS A TEST FOR WATCHES

Program of test.—This test is designed for high-grade pocket watches adjusted for five positions, three temperatures, and for isochronism and is the most complete scheduled watch test conducted by the bureau. The test consists of determining the daily rates in

a series of 15 periods occupying a total time of 54 days. The positions and approximate temperatures are as indicated below. The watches are wound and read once each day, except during the isochronism test (period 11). During this period the watch is not wound, except at the beginning of the test, and observations are made once each hour for the first 12 hours and from the twenty-fourth to the thirty-sixth hour.

Period	Duration	Position	Temperature
1	3 days	Vertical, pendant-up	28° to 30° C. (82° to 86° F.).
2	do	Vertical, pendant-right	Do.
3	do	Vertical, pendant-left	Do.
4	do	Horizontal, dial-up	Do.
5	do	Horizontal, dial-down	Do.
6	do	do	Do.
7	do	Horizontal, dial-up	Do.
8	do	Vertical, pendant-left	Do.
9	do	Vertical, pendant-right	Do.
10	do	Vertical, pendant-up	Do.
11	36 hours	Vertical, pendant-up (isochronism) (Intermediate day.)	Do.
12	5 days	Horizontal, dial-up (Intermediate day.)	5° C. (41° F.).
13	do	Horizontal, dial-up (Intermediate day.)	20° C. (68° F.).
14	do	Horizontal, dial-up (Intermediate day.)	35° C. (95° F.).
15	3 days	Vertical, pendant-up	28° to 30° C. (82° to 86° F.)

Derived results and tolerances.—

No.	Criteria	Tolerance allowed
		Seconds
1	Mean deviation of daily rate	0.75
2	Mean deviation of rate for change of position	3.00
3	Largest difference in rates for any two positions	10.0
4	Rate in horizontal, dial-up position minus rate in vertical, pendant-up position	5.0
5	Rate in horizontal, dial-down position minus rate in horizontal, dial-up position	4.0
6	Progressive change in rate in periods 1 to 10	3.00
7	Recovery of rate	6.0
8	Isochronism error	3.0
9	Difference in rate per degree from 5° to 35° C	.20
10	Difference in rate per degree from 5° to 20° C. minus difference in rate per degree from 5° to 35° C	.30
11	Largest mean daily rate for any period	10.0

Computation of derived results.—The derived results are computed in accordance with the following rules:

1. The "mean deviation of daily rate" is the mean, regardless of sign, of the 48 differences obtained by subtracting each of the 48 daily rates of the 14 periods of the test (period 11 being omitted) from the mean rate of the period in which the daily rate occurs.

2. The "mean deviation of rate for change of position" is the mean, without regard to sign, of the differences between each of the "mean rates" for the five positions and the algebraic mean of the five. The "mean rate" for each position is the average of the mean daily rates for the two periods in the same position.

3. The "largest difference of rate between any two positions" is the largest difference between any two of the "mean rates" for the five positions. (Periods 1 to 10.)

4. The "rate in horizontal, dial-up minus the rate in vertical, pendant-up position" is the difference between the "mean rates" for these two positions taken as indicated.

5. The "rate in horizontal, dial-down minus the rate in horizontal, dial-up position" is the difference between the "mean rates" for these two positions, taken as indicated.

6. The "progressive change in rate in periods 1 to 10" is the algebraic mean of the differences between the mean rate for the first period of the test in each position and the mean rate for the second period in the same position. It indicates the progressive change in rate which has taken place during the position tests.

7. The "recovery of rate" is the difference between the mean rate in period 15 and the mean rate in period 1.

8. The "isochronism error" is the difference between the amount gained or lost in the isochronism test, period 11, in the first 24 hours after winding, and twice the amount gained or lost in the first 12 hours after winding.

9. The "difference in rate per degree from 5° to 35° C." is the difference between the mean rate in period 14 and the mean rate in period 12 divided by the difference in temperature in ° C. for the same two periods.

10. The "difference in rate per degree from 5° to 20° C. minus the difference in rate per degree from 5° to 35° C." is the difference between the two rates, taken as indicated. The difference in rate per degree from 5° to 20° C. is the difference between the mean rate in period 13 and the mean rate in period 12 divided by the difference in temperature in ° C. for the same two periods.

This criterion shows the uniformity of the change in the daily rate with temperature. This quantity, when averaged without regard to sign, with the result obtained in criterion 9 serves as a joint measure of the temperature compensation, and is used as the term c in the formula for calculating relative performance.

11. The "largest mean daily rate for any period" is the largest mean rate for any of the 15 periods, omitting the isochronism test, period 11.

Relative performance.—For watches which do not exceed any of the tolerances of this test, a "relative performance" is computed in accordance with the following formula:

$$\text{Relative performance} = 30\frac{(1-a)}{0.75} + 30\frac{(1-b)}{3.00} + 30\frac{(1-c)}{0.25} + 10\frac{(1-d)}{6.0}$$

in which

a = the mean deviation of daily rate as computed in criterion 1.

b = the mean deviation of rate for change of position as computed in criterion 2.

c = the arithmetical mean of the difference in rate per degree from 5° to 35° C., as computed in criterion 9, and the amount by which the difference in rate per degree from 5° to 20° C. differs from the difference in rate per degree from 5° to 35° C.

d = the recovery of rate, as computed in criterion 7.

6. The "recovery of daily rate for the five recovery differences" is the arithmetical mean of the five recovery differences found in computing criterion 5 above.

7. The "largest mean daily rate of any period" is the largest mean daily rate obtained in any period except period 7.

Certificates and reports.—A certificate is issued for each chronometer which does not exceed any of the tolerances in this test. A report is issued for each chronometer which fails to meet one or more of the tolerances. The certificate or report is accompanied by curves showing the effects of temperature changes upon the daily rate and the results of the isochronism test. The mean daily rate for each period of the test and the derived results explained above are also given.

V. GENERAL INSTRUCTIONS TO APPLICANTS FOR TESTS

1. APPLICATION FOR TEST

All timepieces submitted for test should be accompanied by a written request stating the particular standard test desired, and listing the timepieces submitted. Timepieces may be submitted by one person with the request that the certificate or report be made out in the name of another person; or the purchaser of a timepiece, in placing an order, may direct that the timepiece be sent to this bureau for test before being forwarded to the purchaser. In such instances, the request for the test should state whether the timepiece, in case of failure to pass the test and receive a certificate, should be returned to the person from whom it was purchased or be forwarded to the purchaser.

2. SPECIAL TESTS

The bureau will gladly cooperate with investigators, manufacturers, and others who have particular problems to solve. When no standard test provides the information desired, special tests may be arranged if the work is important and the facilities and time of the bureau permit. Such tests should be arranged by consultation or correspondence before shipment is made.

3. CERTIFICATES AND REPORTS

Certificates are granted for all timepieces found to meet all the requirements of any of the standard tests described in this circular, and reports are issued for those that fail to meet one or more of the requirements. No certificates are granted for special tests, a detailed report of the test being rendered to the applicant.

4. FEES AND REMITTANCES

Fees have been established for the six standard tests described in this circular, and are given in Fee Schedule 231. which may be obtained from the National Bureau of Standards upon request. The fees for special tests depend chiefly upon the time consumed and the amount of alteration required in the regular testing equipment. An estimate of fees for special tests will be furnished upon request. Fees should be remitted by money order or check drawn to the order of the "National Bureau of Standards," and should be sent with the request for test whenever practicable.

5. IDENTIFICATION MARKS

Each separate timepiece should have the name of the manufacturer and a number stamped plainly upon it. This marking will be used as identification in rendering reports of the test.

6. SHIPPING DIRECTIONS

When timepieces are not delivered at the bureau personally they should be securely packed in cases or packages which will not be broken in transportation and which may be used in returning them to the owner. The shipment in both directions is at the applicant's risk. It is recommended that shipment be made by registered mail or express. Great care should be taken in packing. Each instrument should be wrapped in strong paper or other covering to prevent dust from getting into it. The tops of large boxes should be put on with screws, as the jar due to nailing and the subsequent opening is liable to cause damage. All packages should be plainly marked with the shipper's name and address. The tops of the shipping boxes should have the return or forwarding address on the underside. Transportation charges are payable by the person requesting the test. The charges for shipment to the bureau must be prepaid, and, unless otherwise arranged, articles will be returned or forwarded by express "collect."

When timepieces are submitted by one person with instructions to test and forward to another, directions should be given for the disposition of such as may be rejected by the bureau. If such instructions are not given at the time the test is requested, much unnecessary delay may result.

7. BREAKAGE

No risk of breakage will be assumed by the bureau. All possible care will be taken in handling the apparatus submitted for test, but breakage is sometimes unavoidable.

8. ADDRESS

All communications concerning the testing of timepieces and all material for test should be addressed "National Bureau of Standards, Attention Division 2–3, Washington, D. C."

VI. APPENDIX

1. USE AND CARE OF A WATCH

The importance of the careful handling of a fine watch, of regularity in winding it, and of frequently checking its correction with some source of correct time, in order to obtain an accurate indication of time, is so well known as scarcely to need emphasis. However, with the thought of calling the reader's attention to some important details included under the above general head, the following suggestions on the handling, winding, and carrying of a watch are included here.

(a) THE HANDLING OF A WATCH

It is well known that a fall or severe jar is liable to result in injury to the mechanism, especially in the bending of a pivot or the breaking

of a jewel. It is, perhaps, not so well known that the mere fall of a watch to the end of its chain, or the jar it may receive when the article of clothing containing the watch is thrown down or dropped may cause injury to some part of the movement. Therefore, all sudden motions of the watch, even when in the hand, should be avoided.

Likewise care should be taken to keep the parts of the watch from becoming magnetized by proximity to electrical apparatus having strong magnetic fields, such as exist in the neighborhood of large motors and generators.

Unless the watch has a thoroughly dust-proof case care should be taken to keep the pocket free from dirt and lint, and it is desirable to have a watch pocket of a material that gives off a minimum amount of lint. The watchcase should be opened only when necessary and only in places where there is little chance of dust gathering on the movement while it is exposed. A broken watch crystal should be replaced promptly to prevent dirt getting into the mechanism.

(b) THE WINDING OF A WATCH

The importance of the regular winding of a watch will be quickly realized when one sees the isochronism curve of a given watch. Even the delay of a hour in the time of winding may cause considerable variation in the rate in some instances. Sometimes a watch will have a more uniform rate for 24 hours if it is wound twice a day, but it is not a desirable plan to follow unless it is carried out every day, as a watch having comparatively poor adjustment for isochronism may exhibit larger variations of rate when semidaily windings are occasionally omitted than if it were wound only once a day. The practice of winding the watch a little at a time, often absent-mindedly, whenever it is taken from the pocket, is not productive of uniformity of rate. The winding should be done steadily and not too rapidly, and its conclusion should be approached carefully to avoid injury to the spring or winding mechanism.

(c) THE CARRYING OF A WATCH

The pocket in which one carries his watch, the size of the pocket, and the kind of watch chain or fob used have a more important effect on the uniformity of a watch's rate than is generally realized. The temperature of the watch in different pockets varies considerably and the amount of motion and jar to which the watch is subject also varies. For instance, a watch carried in the upper coat pocket generally is at a lower temperature and is more frequently disturbed, as well as being held in various positions more irregularly, than in other pockets. In a large pocket the watch is apt to turn to the right or left by various amounts, giving irregular rates unless one adopts some method to hold it upright. Perhaps the best method to prevent a watch turning in this way (other than actually pinning it in place) is to keep the watch in a chamois or kid watch bag, such as may be obtained from jewelers in correct size to fit one's watch, as the friction of the bag in the pocket prevents its turning. The bag also protects the watch and keeps it clean. Most watch chains and many watch fobs are not effective in holding the watch upright. A fob of the type which hangs over the top of the pocket sometimes holds the watch upright fairly well, but with such a fob there is danger that the watch may be accidentally dropped out of the pocket unless it is held by some kind of safety device.

In case a watch is well regulated for one position and one temperature, but not well adjusted for other positions and temperatures, it is obviously advantageous to keep the watch in that position and at that temperature for which it is best adjusted and regulated for as large a proportion of each 24 hours as is practicable. Also it is often possible by proper selection of position at night to compensate for errors accrued during the day. This compensation of errors by change of position, of course, requires accurate knowledge of the performance of the watch in various positions.

(d) COMPARISONS WITH SOME RELIABLE SOURCE OF STANDARD TIME

The regular daily comparison of one's watch with a reliable regulator, chronometer, or time signals received from some authoritative source will be found very valuable in determining the regularity of the watch's rate.

The actual comparison of a watch with any source of standard time can readily be made to within a half or a quarter of a second, with a little practice. If the comparison is made with a signal beating seconds or with a clock ticking seconds where one can hear the beats, the best method is to count the seconds one hears and note with the eye the second and fraction of a second on the watch when the signal to which one is listening reaches the sixtieth second, or some integral 10-second point, or else, keeping the count of the second beats, note the number of the second and fraction thereof when the second hand of the watch reaches the sixtieth second or some integral 10-second point. If the beat of the comparison clock can not be heard on account of other noises, it will be necessary to get the count of the seconds on the regulator or chronometer by watching the beats of the pendulum or the unlocking of the second hand, and when this is secured read the watch by either process outlined above and then without stopping the count of the seconds look back at the clock to check the count. If in looking at the watch the count has been slightly accelerated or retarded, it may be necessary to repeat the trial to obtain accurate results.

Whether the watch is fast or slow must be determined by a separate rough comparison or, when time signals are being used, by waiting until the end of the signal, if the approximate correction of the watch is unknown. If the daily comparisons of a watch are not made at the same time each day, it is, of course, necessary to interpolate between them to determine the 24-hour rate of the watch.

Any marked departure from such a regular rate usually indicates that the watch needs cleaning or oiling or that some accident has happened to the mechanism. It is always desirable that repairs be made promptly before further damage or wear takes place from the friction of any bent or broken parts. When a watch of high grade and good condition is running well, differences of successive daily rates of not more than two to four seconds may be expected, if the precautions suggested are observed, especially those in regard to the constancy of position and temperature of the watch day and night; otherwise, much larger variations of rate may result.

When the variations of daily rate gradually become larger and the progressive change in rate becomes more pronounced, it is a very

reliable indication that the watch should be cleaned. The frequency with which a watch should be cleaned varies greatly and depends largely upon the usage it has received, such as the exposure to air, to contamination of dirt, fumes, and moisture, and to temperature changes. A watch which under one man's usage may require cleaning every year may, under the care of another man, give as accurate or better results for five years without being serviced. When a watch does require cleaning or repairing it is always important that the work be done by an experienced and reliable watchmaker.

2. STANDARD TIME SIGNALS

The best generally available source of accurate time is the time signal as transmitted by telegraph from the United States Naval Observatory and broadcast by radio from Arlington, Va., and certain other naval stations as listed in the table below.

All naval time signals are made in a standard manner, which is as follows:

The signals begin five minutes before the hour and consist of a dash on each second, except that no dashes are sent on the seconds listed below:

55 minutes; 29, 51, and 56 to 59 seconds.
56 minutes; 29, 52, and 56 to 59 seconds.
57 minutes; 29, 53, and 56 to 59 seconds.
58 minutes; 29, 54, and 56 to 59 seconds.
59 minutes; 29, and 51 to 59 seconds.

Beginning exactly on the hour a much longer dash is sent. In all cases the exact second is denoted by the beginning of the dash, the end being without significance. It will be noted that the number of seconds sounded immediately following the single second omission and preceding the long omission at the end of each minute indicates the number of minutes of the signal yet to be sent. For instance, the signal for 56 minutes and 52 seconds is omitted and then 3 seconds are sounded, indicating that 3 minutes of the signal remain to be transmitted.

These time signals, if received directly and automatically are seldom in error by as much as 0.20 second. The average error is generally less than 0.03 second.

Of the stations listed, the first two automatically transmit the signal as received from the Naval Observatory at Washington, with errors averaging only 0.02 to 0.06 second. Most of the other stations automatically reradiate, and the error is somewhat larger. The signal, however, is sufficiently exact for commercial use.

Radio transmission of time signals [1]

Station	Call letters	Frequency	Wave length	Signal sent
		Kilocycles	*Meters*	
Arlington, Va.	NAA	113	2,653	3 a. m., 12 noon, and 10 p. m., eastern standard time.
		690	434.5	
		4,015	74.7	
		8,870	33.8	
		12,045	24.9	
		16,060	18.7	
Annapolis, Md.	NSS	17.8	16,844	Same as Arlington.
Astoria, Wash. (North Head).	NPE	102	2,939.4	9 a. m. pacific standard time.
Balboa, Canal Zone (Darien).	NBA	46	6,517.8	1 p. m. and 11 p. m. eastern standard time.
Cavite, P. I.	NPO	56	5,353.9	11 a. m. and 10 p. m. Philippine standard time.
		108	2,776.1	
		8,872	33.8	
		13,308	22.5	
Colon, Canal Zone	NAX	132	2,771.4	Same as Balboa.
Eureka, Calif.	NPW	108	2,776.1	9 a. m. pacific standard time.
Great Lakes, Ill.	NAJ	122	2,457.5	12 noon, eastern standard time.
Key West, Fla.	NAR	106	2,828.5	Do.
New Orleans, La.	NAT	104	2,882.9	Do.
Honolulu, T. H. (Pearl Harbor).	NPM	26.1	11,487	1.30 p. m., Hawaiian standard time.
San Diego, Calif. (Chollas Heights).	NPL	30.6	2,798.0	9 a. m. Pacific standard time.
		102	2,939.4	
San Francisco, Calif. (Mare Island).	NPG	42.8	7,005.1	Do.
		66	4,542.7	
		108	2,776.1	

[1] The values given in this table are subject to change by the Navy Department.

The telegraph office in many of the larger cities is provided with a master clock which is set daily, usually at noon, to agree with the signal from the Naval Observatory, and a service is furnished to subscribers of synchronization of other clocks in the city hourly by means of this master clock. If the master clock receives proper attention and is regulated so that its daily rate is small—only a few seconds a day—and, if the subsidiary clocks are in good condition so that they are regularly synchronized, this system furnishes a very satisfactory means of establishing the correct time. The subsidiary clocks, or jewelers' regulators corrected by them, may, therefore, serve as suitable standards for determining the rate of a watch.

It is desirable, however, on account of the possible large rate of the master clock in the telegraph office, to make watch comparisons with such clocks within an hour or two after the time of the Naval Observatory or other signal from which the master clock is set has been received, as thus the effect of the daily rate of the master clock is minimized. Many jewelers, however, have regulators or chronometers which have a very small rate, and, if such timepieces are frequently set correctly by comparison either with a telegraphic time signal or with a synchronized clock immediately after the receipt of the time signal, they will generally serve as accurate sources of time at any period of the day.

3. STANDARD TIME ZONES

The use of standard time in sections differing by integral hour differences of longitude from Greenwich instead of local mean time is nearly universal throughout the civilized world. Practically all the nations of the world have abandoned their local meridian time in favor of time as reckoned from the meridian passing through Greenwich, England.

The United States is divided into four standard time zones, each approximately 15° of longitude in width. All places in a given zone use, instead of their own local time, the time counted from the transit of the "mean sun" [2] across the meridian which passes through the approximate center of that zone.

These time zones are designated as eastern, central, mountain, and Pacific, and the time in these zones is reckoned from the seventy-fifth, ninetieth, one hundred and fifth, and one hundred and twentieth meridians west of Greenwich, respectively. The time in the various zones is slower than Greenwich time by 5, 6, 7, and 8 hours, respectively.

Hence, when it is noon in the eastern time zone it is 11 a. m. in the central time zone, 10 a. m. in the mountain time zone, and 9 a. m. in the Pacific time zone. In traveling from one time zone to another, one must set his watch one hour ahead if traveling eastward and one hour back if traveling westward whenever he crosses a zone boundary.

The question of changing from the time of one time zone to that of an adjacent zone arises in practice largely in the operation of railroads. Because of the inconvenience of changing the time by the necessary amount of one hour at every point where a railroad crosses one of these boundary lines, the more convenient practice has usually been followed of making the change at some terminal or division point on the road, at some junction point, or at the boundary line between the United States and Canada. The result is that practically the boundaries of the time zones are defined by the lines connecting these points of railroad time change. Because of the location of these railroad junctions or terminals the resulting lines are rather irregular.

The boundaries of these time zones in the United States are established by the Interstate Commerce Commission in accordance with an act of Congress dated March 19, 1918. These boundaries have been changed from time to time as circumstances have shown such changes to be advisable. A detailed description of the time zone boundaries in the United States, giving a complete list of the railroads and towns effected is issued by the Interstate Commerce Commission.

A map showing the Standard Time Zones in the United States and Adjacent Parts of Canada and Mexico, known as Bureau of Standards Miscellaneous Publication No. 111, may be obtained from the Superintendent of Documents for 10 cents. Circular 280, Standard Time Throughout the World published by the National Bureau of Standards and available from the Superintendent of Documents, Government Printing Office, for 5 cents, gives a list of the times used in various countries of the world.

Bureau of Standards Miscellaneous Publication No. 84, Standard Time Conversion Chart, which gives a graphical illustration of the time zones of the world, and furnishes an easy means of converting time in one zone to that in another, may be secured from the Superintendent of Documents for 10 cents.

WASHINGTON, February 27, 1931.

[2] The interval between successive passages of the sun across the meridian is somewhat variable, and for this reason apparent solar days are of unequal length. Therefore, mean time has been adopted, which is kept by a fictitious or "mean sun" moving uniformly in the plane of the Equator at the same average speed as that of the real sun, thus making days of equal length. It is "mean noon" when this "mean sun" crosses the meridian.

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